Segregated Deployment of Downhole Valves for Monitoring and Control of Multilateral Wells

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SEGREGATED DEPLOYMENT OF DOWNHOLE VALVES FOR MONITORING AND CONTROL OF MULTILATERAL WELLS

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BACKGROUND

The present invention relates generally to operations performed and equipment utilized in conjunction with a subterranean well and, in an embodiment described herein, more particularly provides a well completion, system and method for controlling and monitoring fluid flow in multilateral wells.

It is typical practice when controlling and/or monitoring production flow from a lateral or branch wellbore, and from a portion of a main or parent

wellbore below an intersection between the main and branch wellbores, to use one or more flow control devices and/or sensors positioned in the main wellbore. Unfortunately, this means that a flow control device/sensor used to control/monitor production from the branch wellbore may be positioned a relatively large distance from a zone in which the production originates.

Even a flow control device/sensor used to control/monitor production from a lower portion of the main wellbore may be positioned a relatively large distance from a zone in which the production originates, for example, when the flow control device/sensor is positioned above an intersection between the main and branch wellbores. Flow between a wellbore and a zone intersected by the wellbore is more conveniently and accurately monitored and controlled when a device used to monitor/control such flow is positioned in the wellbore in closer proximity to the zone.

Lines, such as hydraulic, electric, fiber optic, etc. lines, which are used to remotely operate and communicate with the flow control devices and sensors may be attached to a tubing string on which the flow control devices and sensors are conveyed into a well. If flow control devices and sensors are to be positioned in branch wellbores as well as in the main wellbore, there exists a need to conveniently and reliably provide for the lines extending into the branch wellbore(s), without requiring interruptions (breaks or disconnections) in the lines or requiring lines to be "wet" connected while downhole.

Therefore, it will be readily appreciated that there exists a need for improved well completions, systems and methods to address these problems and/or other problems in the art of completing multilateral wells. These improvements will also be useful in other applications.

SUMMARY

In carrying out the principles of the present invention, in accordance with an embodiment thereof, a well completion, completion system and method are provided which alleviate the above problems in the art.

In one aspect of the invention, a well completion system is provided. The well completion system includes at least one line extending to a remote location and into at least first and second intersecting wellbores. The line is positioned in the first and second wellbores without making a connection in the line downhole.

In another aspect of the invention, a well completion system includes two or more tubular strings. One of the tubular strings extends in a wellbore, and another tubular string extends in another wellbore intersecting the first wellbore. Lines are attached to the tubular strings. At least one of the lines extends with the first tubular string in the first wellbore, and at least one of the lines extends with the other tubular string in the other wellbore.

In yet another aspect of the invention, a method of completing a well including intersecting wellbores is provided. The method includes the steps of:

conveying at least one line into each of the wellbores; and performing the conveying step without making any connections in the line in the well.

These and other features, advantages, benefits and objects of the present invention will become apparent to one of ordinary skill in the art upon careful consideration of the detailed description of representative embodiments of the invention hereinbelow and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a partially cross-sectional schematic view of an initial configuration of a well completion system embodying principles of the present invention;

FIG. 2 is a partially cross-sectional view of a final configuration of the well completion system of FIG. 1;

FIG. 3 is a partially cross-sectional schematic view of an initial configuration of another well completion system embodying principles of the present invention;

FIG. 4 is a partially cross-sectional view of a final configuration of the well completion system of FIG. 3;

FIG. 5 is a schematic partially cross-sectional view of a third well completion system embodying principles of the invention; and

FIG. 6 is a schematic partially cross-sectional view of a fourth well completion system embodying principles of the invention.

DETAILED DESCRIPTION

Representatively illustrated in FIG. 1 is a multilateral well completion system 10 which embodies principles of the present invention. In the following description of the system 10 and other apparatus and methods described herein, directional terms, such as "above", "below", "upper", "lower", etc., are used for convenience in referring to the accompanying drawings. Additionally, it is to be understood that the various embodiments of the present invention described herein may be utilized in various orientations, such as inclined, inverted, horizontal, vertical, etc., and in various configurations, without departing from the principles of the present invention.

As depicted in FIG. 1, a tubular string 12, such as a production tubing string, is being used to convey two other tubular strings 14, 16 into a parent or main wellbore 18, The main wellbore 18 may be lined with protective casing or liner 20, or any portion of the wellbore may be completed open hole, if desired.

Another branch or lateral wellbore 22 intersects the main wellbore 18 at an intersection 24. The branch wellbore 22 may be lined with a liner 26, or any portion of the branch wellbore may be completed open hole, if desired.

A whipstock or deflector 28 is positioned in the main wellbore 18 adjacent and just below the intersection 24. As used herein, the term "below" means relatively farther along a wellbore from the earth's surface. Conversely, the term "above" means relatively closer to the earth's surface along a wellbore. Thus, the terms "above" and "below" may accurately describe a relative position in a wellbore, even if the wellbore is horizontal.

The deflector 28 may have been used to drill the branch wellbore 22, or it may have been positioned in the main wellbore 18 after drilling the branch wellbore. The deflector 28 includes a bore 30 extending longitudinally therethrough. An upper inclined surface 32 of the deflector 28 is oriented so that it faces toward the branch wellbore 22.

An assembly 34 is positioned in the main wellbore 18 below the deflector 28, and a similar assembly 36 is positioned in the branch wellbore 22. Each of the assemblies 34, 36 includes a seal bore 38 attached to, or otherwise associated with, a sealing and anchoring device 40, such as a packer or liner hanger, etc.

Each of the tubular strings 14, 16 includes a sealing device 42, such as seals, packing, etc., for sealing engagement in a respective one of the seal bores 38. Alternatively, the sealing device 42 on the tubular string 16 could sealingly engage the bore 30 of the deflector 28. Any manner or location of sealing engagement between the tubular strings 14, 16 and the wellbores 18, 22 may be used, in keeping with the principles of the invention.

Also included in each of the tubular strings 14, 16 is a flow control device 44, such as a valve or choke, etc., and a sensor 58. Preferably, the flow control devices 44 are remotely controlled, for example, via one or more lines 46 extending to a remote location, such as the earth's surface or another position in the well. The sensors 58 also communicate with the remote location via the lines 46.

The lines 46 may be hydraulic, electric, fiber optic, or another type of line. Alternatively, or in addition, the flow control devices 44 and/or sensors 58 may be controlled and/or monitored remotely via telemetry without use of the lines 46. For example, the flow control devices 44 and sensors 58 could be controlled and/or monitored remotely using acoustic, pressure pulse, electromagnetic, or any other type of telemetry.

The flow control devices 44 may be Interval Control Valves commercially available from WellDynamics, Inc. of Spring, Texas. These Interval Control Valves not only control flow between a tubular string and a zone intersected by a wellbore, they may also include the ability to monitor certain well parameters. For example, an optical fiber in one of the lines 46 connected to the flow control devices 44 may be used in distributed temperature sensing.

If desired, the relative longitudinal positions of the flow control devices 44 and sealing devices 42 as depicted in FIG. 1 may be reversed in the tubular strings 14, 16, since the Interval Control Valves are designed to regulate flow laterally through their sidewalls, rather than between upper and lower ends thereof. The

flow control devices 44 may control flow through a longitudinal passage formed through each device, or through a sidewall of each device, in keeping with the principles of the invention.

The sensors 58 may include pressure, temperature, flow rate, resistivity, fluid identification, water cut, or any other type of sensors. As with the flow control devices 44, the relative position of the sensors 58 in the tubular strings 14, 16 may be changed, if desired. The sensors 58 may be positioned internal or external to the tubular strings 14, 16, and may detect properties of substances internal or external to the tubular strings.

A junction 48 is provided between the tubular strings 12, 14, 16. Via the junction 48, each of the tubular strings 12, 14, 16 is in communication with each of the other tubular strings. This is similar in many respects to the Isolated Tie-Back System commercially available from Halliburton Energy Services, Inc. of Houston, Texas. However, it should be clearly understood that such communication between the tubular strings 12, 14, 16 is not necessary in keeping with the principles of the invention.

The tubular string 14 includes a bull nose 50 at a lower end thereof, in order to deflect the tubular string into the branch wellbore 22. That is, the deflector 28 is configured so that it is selective, deflecting the tubular string 14 off of the surface 32 into the branch wellbore 22, but permitting the tubular string 16 to pass through the bore 30 and into a lower portion 52 of the main wellbore 18. For example, the bull nose 50 may have a larger outer diameter than an inner

diameter of the bore 30, the bull nose may be shaped in a manner otherwise preventing it from passing into the bore, etc.

Alternatively, the tubular string 16 could be longer than the tubular string 14, so that the tubular string 16 enters the bore 30 first. Then, as the tubular string 12 is lowered further, the presence of the tubular string 16 in the bore 30 prevents the tubular string 14 from entering the bore, and so the tubular string 14 is deflected by the surface 32 into the branch wellbore 22. An illustration of this alternative is provided in FIGS. 3 & 4, and is described in further detail below.

Referring additionally now to FIG. 2, the system 10 is representatively illustrated in a configuration in which the tubular string 14 has been deflected into the branch wellbore 22, and the tubular string 16 has passed through the bore 30 into the lower portion 52 of the main wellbore 18. The sealing devices 42 on the tubular strings 14, 16 have sealingly engaged the respective bores 38 of the assemblies 36 in the branch wellbore 22 and in the lower portion 52 of the main wellbore 18. Alternatively, the sealing devices 42 could sealingly engage other structures in the wellbores 18, 22, for example, the sealing devices could be packers or liner hangers which sealingly engage the casing 18 and liner 26, without use of the assemblies 34, 36.

The flow control devices 44 on the tubular strings 14, 16 may now be used to control fluid flow between the respective tubular string and the branch wellbore 22 or the lower portion 52 of the main wellbore 18. The flow control device 44 on the tubular string 14 may now be used to control flow (production or

injection) between the tubular string and a formation or zone 54 intersected by the branch wellbore 22, and the flow control device on the tubular string 16 may now be used to control flow (production or injection) between the tubular string 16 and a formation or zone 56 intersected by the lower portion 52 of the main wellbore 18. Note that the zones 54, 56 may be separate portions of the same zone or formation, and one of the tubular strings 14, 16 may be used for injection while the other is used for production, etc.

Note that the flow control devices 44 are positioned in close proximity to the respective zones 54, 56, enhancing the proper and accurate operation of the flow control devices to achieve a desired rate or quantity of flow therethrough. Monitoring parameters of the well completion using the sensors 58 is also performed in close proximity to the zones 54, 56, thereby enhancing the accuracy of these measurements. The ability to remotely control the flow control devices 44 and monitor the sensors 58 via the lines 46, coupled with the enhanced accuracy provided by the positioning of the flow control devices and sensors, permits precise control and monitoring of production and/or injection operations in the well.

Furthermore, note that the lines 46 attached to the tubular strings 12, 14, 16 are installed in a manner that does not require interruptions in the lines and does not require any "wet" connections between lines while downhole. Instead, the lines 46 continue to be operably connected to the flow control devices 44 and

sensors 58, and extend unbroken to the remote location, during the installation of the tubular strings.

Referring additionally now to FIG. 3, another multilateral well completion system 60 is representatively illustrated. The system 60 is similar in many respects to the system 10 described above, and so elements of the system 60 which are similar to elements of the system 10 described above are indicated in FIG. 3 using the same reference numbers.

As depicted in FIG. 3, the tubular strings 12, 14, 16 are being conveyed into the main or parent wellbore 18, similar to the system 10 as shown in FIG. 1. However, another branch wellbore 62 intersects the main wellbore 18 at an intersection 64. A deflector 66 has been positioned just below the intersection 64, and has been oriented so that an upper inclined deflection surface 68 faces toward the branch wellbore 62.

The deflector 66 has a bore 70 extending therethrough which is large enough for the tubular strings 14, 16 to pass through side-by-side. Thus, as the tubular strings 12, 14, 16 are further lowered in the main wellbore 18, the tubular strings 14, 16 will both enter the bore 70 and pass through the deflector 66.

Referring additionally now to FIG. 4, the system 60 is depicted in a configuration in which the tubular strings 14, 16 have passed through the deflector 66. Further conveyance of the tubular strings 12, 14, 16 into the main wellbore 18 causes the tubular string 14 to deflect off of the deflector surface 32 and into the branch wellbore 22, as described above for the system 10. Still

further conveyance of the tubular strings 12, 14, 16 into the main wellbore 18 causes the tubular string 16 to enter the bore 30 of the deflector 28, also as described above for the system 10.

Another tubular string 72 is connected to the tubular string 12 by means of another junction 48. The tubular string 72 is similar to the tubular string 14, in that it includes a sealing device 42, a flow control device 44 and a sensor 58. The lines 46 extend to the flow control device 44 and sensor 58 on the tubular string 72.

The junction 48 provides communication between the tubular strings 12, 72 and another tubular string 74 connected thereabove and extending to a remote location. The tubular string 74 is, thus, used to convey the other tubular strings 12, 14, 16, 72 into the main wellbore 18.

As the tubular string 74 conveys the other tubular strings 12, 14, 16, 72 into the main wellbore 18, the tubular strings 14, 16 pass through the deflector 66, as described above. The tubular string 12 also enters the bore 70 of the deflector 66 after the lower junction 48 enters the bore 70. Thus, when the lower end of the tubular string 72 reaches the deflector 66, the tubular string 12 is already in the bore 70.

The tubular string 72 includes a bull plug 76 or other device at its lower end which prevents the tubular string 72 from entering the bore 70 while the tubular string 12 is in the bore. For example, the bull plug 76 may be sized or otherwise configured so that it cannot fit into the bore 70 while the tubular string

12 is in the bore. Instead, the tubular string 72 is deflected by the surface 68 into the branch wellbore 62.

The tubular string 72 may be deflected into the branch wellbore 62 at about the same time as the tubular string 14 is deflected into the branch wellbore 22. Of course, depending upon the relative lengths of the tubular strings 12, 14, 16, 72 and relative positions of the deflectors 28, 66, the tubular string 72 may be deflected into the branch wellbore 62 before or after the tubular string 14 is deflected into the branch wellbore 22.

With the tubular strings 12, 14, 16, 72, 74 positioned as depicted in FIG. 4, the sealing devices 42 are set or otherwise sealingly engaged in the respective wellbores 18, 22, 62. Note that, as depicted in FIG. 4, the sealing device 42 on the tubular string 14 is sealingly engaged with the liner 26, the sealing device 42 on the tubular string 16 is sealingly engaged in the bore 30, the sealing device 42 on the tubular string 72 is sealingly engaged in a liner 78 in the branch wellbore 62, and a sealing device 42 on the tubular string 12 is sealingly engaged in the bore 70. Of course, the sealing devices 42 may be otherwise positioned in the wellbores 18, 22, 62, and may be otherwise sealingly engaged in the wellbores, in keeping with the principles of the invention.

In a producing well, the flow control device 44 on the tubular string 14 can now control fluid flow from the zone 54, the flow control device 44 on the tubular string 16 can now control flow from the zone 56, and the flow control device 44 on the tubular string 72 can now control fluid flow from a formation or zone 80

intersected by the wellbore 62. The sensors 58 can be used to monitor these respective fluid flows, or to detect other parameters in the well.

The lower junction 48 commingles the flows from the tubular strings 14, 16 into the tubular string 12. The upper junction 48 commingles the flows from the tubular strings 12, 72 into the tubular string 74 for production to the surface. For an injection well, these flow directions may be reversed.

Note that, in the system 60, the lines 46 are extended into multiple branch wellbores 22, 62, while also extending in the main wellbore 18. This positioning of the lines 46 is accomplished in the system 60 without interruptions in the lines and without requiring any "wet" connections between lines downhole. Instead, the lines 46 extend continuously from the sensors 58 and flow control devices 44 to the remote location. This enhances the reliability and performance of the lines 46, while reducing the complexity of the completion operation.

In FIG. 4, the lines 46 extend through the sealing device 42 on the tubular string 12. This configuration may be accomplished at the surface using "dry" connections (i.e., connections made between lines while at the surface) at upper and lower ends of the sealing device 42, without compromising the reliability or performance of the lines when installed.

Although only two branch wellbores 22, 62 are depicted in FIGS. 3 & 4, it will be readily appreciated that any increased number of branch wellbores may be provided for by increasing the number of tubular strings deflected into the respective branch wellbores, and increasing the number of deflectors, junctions,

flow control devices, sensors, etc., as needed. The lines 46 can extend into any number of branch wellbores to any number of flow control devices, sensors, etc., without interruptions in the lines and without requiring any "wet" connections between lines downhole.

Referring additionally now to FIG. 5, another well completion system 90 is representatively illustrated. The system 90 is similar in many respects to the systems 10, 60 described above, and so elements of the system 90 which are similar to elements of the systems 10, 60 described above are indicated in FIG. 5 using the same reference numbers.

As depicted in FIG. 5, a tubular string 92 is deflected off of the inclined surface 32 of the deflector 28 and into the branch wellbore 22. The tubular string 92 is connected to another tubular string 94 via a junction or wye block 96. The wye block 96 permits access to each of the tubular strings 92, 94, and flow through each of the tubular strings is commingled in the wye block.

The tubular string 94 is sealingly engaged in the bore 30 of the deflector 28. Attached below the deflector 28 is another tubular string 98 positioned in the lower portion 52 of the main wellbore 18. The tubular string 98 is installed with the deflector 28 and anchoring device 40 prior to conveying the tubular strings 92, 94 into the well using the tubular string 12.

The tubular string 98 has the flow control device 44, lines 46 and sensor 58 interconnected therein when it is installed. In order to connect the lines 46 on the tubular string 98 to the lines 46 on the tubular string 94, a "wet" connection

100 is made when the tubular string 94 is engaged with the deflector 28. For example, one connector may be attached to the deflector 28 and operably coupled to the lines 46 on the tubular string 98, while another connector may be attached to the tubular string 94 and operably coupled to the lines on the tubular string 94. When the tubular string 94 is inserted into the bore 30, the connectors mate to form the connection 100.

Although the system 90 does include the "wet" connection 100, it is positioned in the main wellbore 18 where it is more conveniently accessible in the event of a malfunction. Note that the lines 46 on the tubular string 92 extending into the branch wellbore 22 extend continuously from the flow control device 44 and sensor 58 to the remote location, without requiring any "wet" connections to be made downhole.

Referring additionally now to FIG. 6, another well completion system 110 is representatively illustrated. The system 110 is similar in many respects to the systems 10, 60, 90 described above, and so elements of the system 110 which are similar to elements of the systems 10, 60, 90 described above are indicated in FIG. 6 using the same reference numbers.

As depicted in FIG. 6, a tubular string 112 is deflected off of the inclined surface 32 of the deflector 28 and into the branch wellbore 22. The sealing device 42 carried on a lower end of the tubular string 112 sealingly engages the assembly 36 previously positioned in the branch wellbore 22, for example, by sealingly engaging the anchoring device 40.

An upper end of the tubular string 112 remains in the main wellbore 18 and is connected to a junction 114 secured in the main wellbore by an anchoring device 116, such as a packer. The junction 114 has an inner passage 118 which provides fluid communication between the tubular string 112 and an annulus 120 formed between the tubular string 12 and the main wellbore 18 above the junction. An opening 122 in the tubular string 12 permits fluid communication between the annulus 120 and the interior of the tubular string.

Another tubular string 124 extends downwardly from the junction 114 and is sealingly engaged in the bore 30 of the deflector 28. Similar to the system 90 depicted in FIG. 5, the tubular string 98 is connected below the deflector 28 and is installed in the main wellbore 18 prior to running the junction 114 and tubular strings 112, 124 into the well. The "wet" connection 100 is made between the lines 46 connected to the tubular string 98 and the lines connected to the tubular string 124 when the tubular string 124 engages the deflector 28.

The tubular string 124 is in fluid communication with another passage 126 formed through the junction 114. The passage 126 is, in turn, in fluid communication with the tubular string 12. Thus, fluids from the tubular strings 124, 112 are commingled in the tubular string 12. The tubular string 12 is sealingly engaged with the junction 114 by means of seals 128 carried on the tubular string, which are inserted into the passage 126, or into a seal bore at an upper end of the passage.

When the tubular string 12 engages the junction 114, another "wet" connection 100 is formed between the lines 46 attached to the tubular string 12 and the lines 46 attached to the junction 114. As with the connection 100 between the lines 46 attached to the tubular string 124 and the lines 46 attached to the deflector 28, the connection between the lines 46 attached to the tubular string 12 and the lines 46 attached to the junction 114 is made in the main wellbore 18 where it is most conveniently accessible in case of a malfunction.

Note that the lines 46 extending into the branch wellbore 22 do not require a "wet" connection in the branch wellbore or at the intersection 24. Furthermore, it is not necessary for the connection 100 between the lines 46 attached to the tubular string 12 and the lines 46 attached to the junction 114 to be made in the wellbore 18, since the junction 114 and the tubular strings 112, 124 could be conveyed together into the well, instead of installing the junction and tubular strings 112, 124 in the well prior to running in the tubular string 12.

One advantage to using the junction 114 is that it includes another passage 130 which provides access from the passage 126 to the passage 118 when a sleeve 132 is retrieved from, or shifted in, the junction. As depicted in FIG. 6, access to the lower main wellbore 52 is available via the tubular string 12, the passage 126, the tubular string 124 and the tubular string 98. Access to the branch wellbore 22 may be obtained by retrieving or shifting the sleeve 132 and installing a deflector (not shown) in the passage 126 to deflect tools, equipment, etc. from the passage

126, through the passage 130 into the passage 118, and then through the tubular string 112.

Of course, a person skilled in the art would, upon a careful consideration of the above description of representative embodiments of the invention, readily appreciate that many modifications, additions, substitutions, deletions, and other changes may be made to these specific embodiments, and such changes are contemplated by the principles of the present invention. Accordingly, the foregoing detailed description is to be clearly understood as being given by way of illustration and example only, the spirit and scope of the present invention being limited solely by the appended claims and their equivalents.